June 2, 1970 R. H. VONDEROHE ET AL 3,515,486

OPTICAL RANGING DEVICE

Filed Nov. 22, 1967 2 Sheets-Sheet 1

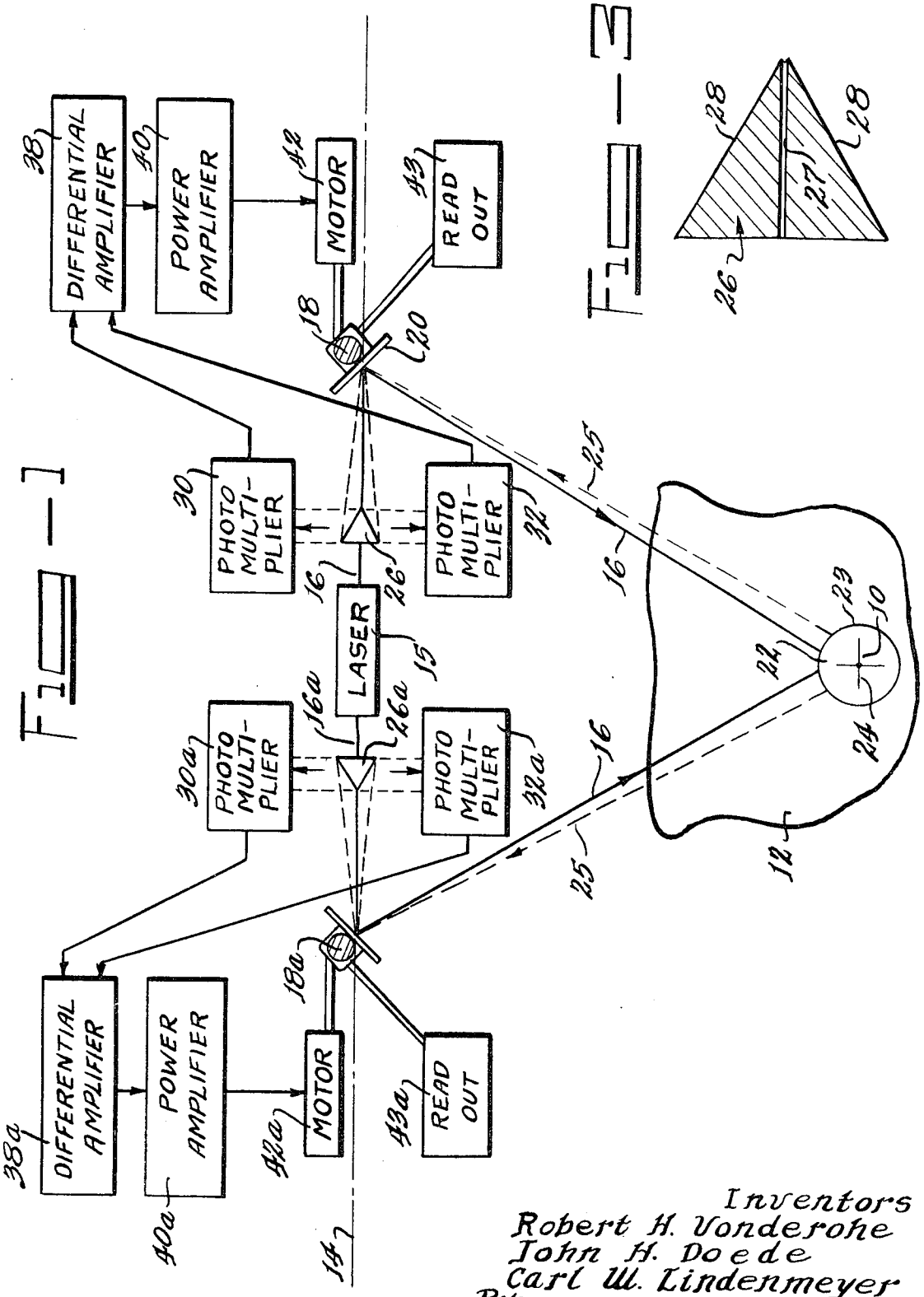


FIG. 1

FIG. 2

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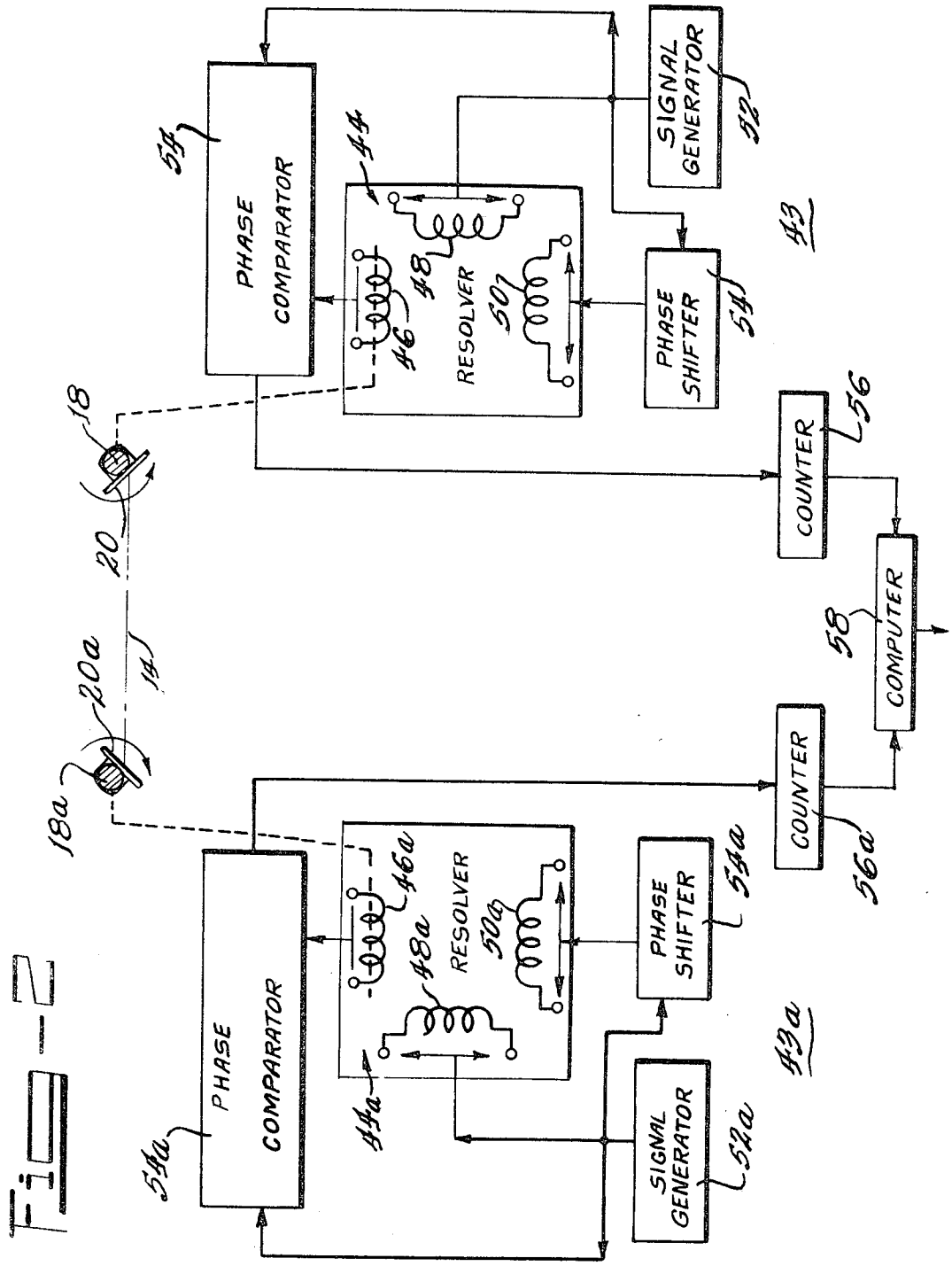


Fig. 2

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United States Patent Office 3,515,486 Patented June 2, 1970

3,515,486

OPTICAL RANGING DEVICE

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Filed Nov. 22, 1967, Ser. No. 685,178
Int. Cl. G01b 11/27
U.S. Cl. 356—152 9 Claims

ABSTRACT OF THE DISCLOSURE

A CW laser transmits a collimated light beam of circular cross section along a reference line to a flat rotatable mirror which reflects the beam to a curved mirror located at an object point. The curved mirror reflects the collimated light with an elliptical cross section back along its transmitted path to a beam splitter located intermediate the flat mirror and the laser along the reference line. The beam splitter divides the reflected elliptical light into two beams whose intensities are proportional to deviation of the reflected elliptical light from the reference line. Differential light responsive means derives a signal from the dual beam output from the beam splitter to drive the rotatable flat mirror and effect axial coincidence between transmitted and reflected light. A resolver and phase comparator determine the angular rotational position of the flat mirror to provide a measure of the spatial position of the object point relative to the reference axis.

CONTRACTUAL ORIGIN OF THE INVENTION

The invention described herein was made in the course of, or under, a contract with the United States Atomic Energy Commission.

BACKGROUND OF THE INVENTION

This invention relates to ranging devices and more particularly to an optical ranging device using collimated light.

Ranging devices are employed to determine the location of a specific point or object with respect to a reference system. These devices may be mechanical, electrical, optical or combinations thereof. One specific use for ranging devices is in conjunction with experiments in high-energy physics. The end product of many of these experiments is a bubble chamber photograph which is generally scanned, and if certain information is found, catalogued or referenced.

Obviously, the accuracy of the information derived from the photographs is dependent upon the means by which the photographs are catalogued or referenced. It is the principal object of this invention to provide an extremely accurate optical ranging device.

SUMMARY OF THE INVENTION

This invention comprises means for generating and transmitting a collimated beam of light along a reference line. Flat rotatable mirrors located at specific points on the reference line reflect the light beam to an object point spaced therefrom. A curved mirror at the object point reflects the light beam back to the flat mirrors and then along the reference line. A combination of beam splitters and photomultipliers detect any deviation from the reference line of the light reflected from the object point and the signal therefrom is used to rotate the flat mirrors until a null deviation between the light reflected from the object point and the reference line is obtained. Means are provided to measure the angular rotation of the mirrors necessary to produce the null deviation, which angular rotation is a measure of the spatial position of the object point with respect to the reference line.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic of an apparatus for the practice of the present invention.

FIG. 2 is a detailed schematic of the readout device of the apparatus of FIG. 1.

FIG. 3 is an enlarged cross-sectional view of the beam splitter in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, an object point **10** is located on a projection area **12**. A reference line **14** is located adjacent projection area **12** and the apparatus of the present invention determines the spatial relationship of point **10** with respect to the reference line **14**. It is apparent from FIG. 1 that the apparatus of the present invention comprises two identical sets of equipment. For purposes of clarity and ease of understanding, the following description will be limited to one set of equipment, it being understood that the other set, designated by the subscript *a*, is identical thereto and operates in a like manner.

A laser **15** is mounted with respect to the reference line **14** so as to generate therealong a collimated beam of light **16** circular in cross section. A shaft **18** is located a predetermined distance from laser **15** along reference line **14** and has a flat mirror **20** attached thereto to rotate therewith. The shaft **18** and mirror **20** are mounted so that mirror **20** reflects light beam **16** from laser **15** onto projection area **12** in the direction of object point **10**.

A movable curved reflector **22** is disposed on the projection area **12**. The curved reflector **22** is a right circular cylinder with transparent top and bottom surfaces which are marked with cross hairs **24**. The cross hairs **24** are located on the top and bottom surfaces of the curved reflector **22** at the center thereof so that a beam of light striking the perimeter of the reflector normal thereto would pass through the center of the cross hairs if not reflected. The perimeter **23** of the reflector **22** is coated with a reflecting material to reflect light incident thereon.

A beam splitter **26** is wedge-shaped and, as shown in FIG. 3, has a circular hole **27** therethrough of a diameter sufficient to admit the light beam **16** from laser **15**. The beam splitter **26** has silvered sides **28** and is mounted with respect to reference line **14** so that the beam **16** from laser **15** passes through hole **27**. Two photomultipliers **30** and **32** are positioned on either side of the beam splitter **26** to detect light reflected from beam splitter **26**. The output of each photomultiplier **30** and **32** is fed to a differential amplifier **38**. The output of differential amplifier **38** is fed via a power amplifier **40** to a motor **42** which is coupled to shaft **18** to cause rotation thereof.

In operation, the laser **15** produces and transmits a collimated light beam **16** along reference line **14** through the hole **27** in beam splitter **26** to the flat mirror **20** mounted on shaft **18**. Mirror **20** reflects light beam **16** onto projection area **12**. The reflector **22** is moved to intercept the light beam **16** which is reflected onto the projection area **12**. The reflector **22** is then positioned so that the intersection of cross hairs **24** is directly over object point **10**. The silvered perimeter **23** of reflector **22** reflects the light beam back to the mirror **20** and back along reference line **14** to the beam splitter **26**. As the silvered perimeter **23** of reflector **22** is curved, the reflected beam **25** will be elliptical in cross section rather than circular. The elliptical reflected light beam **25** due to its enlarged cross section will not pass entirely through the hole **27**

in beam splitter **26** and a portion thereof will be split and reflected by the silvered sides **28** of the beam splitter to the associated photomultipliers **30** and **32**. The output of each of the photomultipliers **30** and **32** is a voltage which is proportional to the integrated intensity of light striking the photomultipliers.

The differential amplifier **38** compares the outputs of the photomultipliers **30** and **32** and produces an output signal therefrom with a polarity indicative of any inequality in outputs from photomultipliers **30** and **32**. The output from the amplifier **38** drives the motor **42** to rotate shaft **18** in a direction to achieve axial coincidence of the elliptical reflected beam **25** with the reference line **14**, at which time the light reflected by sides **28** of beam splitter **26** to the associated photomultipliers **30** and **32** is equal in intensity. Coincidence or null deviation of the elliptically reflected beam **25** with reference line **14** can only occur if beam **16** strikes the perimeter **23** of reflector **22** normal thereto. But, as stated previously, a beam striking the perimeter **23** of reflector **22** normal thereto would pass through cross hairs **24** if the perimeter were not silvered. Thus, with the cross hairs **24** positioned over object point **10** and the elliptical reflected beam **25** in axial coincidence with the reference line **14**, the angular rotational position of shaft **18** is a measure of the angle formed between the reference line and a line drawn between the object point and the shaft. The aforementioned angle is determined by the readout apparatus **43**.

To read out the angular rotational position of shaft **18** and determine the position of point **10** with respect to the reference line **14**, the apparatus **43** shown in detail in FIG. 2 is used.

A resolver **44** has its rotor **46** connected to rotate with shaft **18**. The resolver **44** has stator windings **48** and **50** that are wound in quadrature with respect to each other. The output of a signal generator **52** excites one of the stator windings (for purposes of illustration, stator winding **48**). The output of the signal generator **52** also excites the other stator winding **50** after being passed through a phase shifter **54** wherein the phase of the exciting signal is shifted 90 electrical degrees. The induced output signal of the rotor winding **46** is responsive to the angular position of the rotor with respect to the stator windings **48** and **50**. A phase comparator **54** has two inputs, one connected to the output of the rotor winding **46** and the other to the output of the signal generator **52**. The output from phase comparator **54** is fed to a high-frequency counter **56** and the output therefrom is fed to a computer **58**.

In operation, shaft **18** rotates as explained above until an axial coincidence between the elliptical reflected beam **25** and the reference line **14** is achieved. As shaft **18** rotates, the rotor **46** of resolver **44** rotates therewith so that after shaft **18** reaches its final position, rotor **46** has usually changed its angular position with respect to stator windings **48** and **50**. The signal which is induced in rotor winding **46** by the presence of a signal in stator windings **48** and **50** is phase dependent upon the angular rotational relationship between the rotor windings and the stator windings. Phase comparator **54** compares the phases of the signals from the rotor winding **46** and the signal generator **52** to produce an output signal which is phase dependent upon the angular rotational position of shaft **18**. The output signal from phase comparator **54** is fed to a high speed counter **56** which counts during the time that the signal from the phase comparator is positive. The output from counter **56** is then also a measure of the angular position of shaft **18** and is fed to a computer **58** which is programmed to translate the signal from counter **56** to an angle value. The angle value determined by computer **58** is the angle formed between the reference line **14** and a line drawn from object point **10** to shaft **18**.

This information is duplicated by the series "*a*" equipment to obtain a second angle between reference line **14** and a line drawn from object point **10** to shaft **18***a*. The two angles thus determined in combination with the known distance between shafts **18** and **18***a* permit triangulation of point **10** with respect to the reference line **14**.

Using the preferred embodiment of the device as described above, a high degree of precision is attainable. The accuracy of the position of object point **10** is a function of the distance from flat mirrors **18** and **18***a* and to the object point. When a high-frequency counter, one which varies from 0 to 100,000 counts for a 45-degree rotation of shaft **18**, is used for counter **56**, accuracies of ± 0.00113 inch for a distance of 3 feet from rotatable shafts **18** and **18***a* to object point **10** and ± 0.000377 inch for 1 foot from shafts **18** and **18***a* to the object point are obtainable.

While the above-described apparatus is preferred, the angle formed between object point **10** and reference line **14** at shaft **18** can be determined in another manner. Motor **42** can be operated to drive shaft **18** at a constant speed. Two null signals from differential amplifier **38** will occur for each complete rotation of shaft **18** and mirror **20**. One null will occur as hereinbefore described when the reflected elliptical beam **25** is coincident with beam **16**. The second null will occur when mirror **20** is normal to reference line **14** and beam **16** is reflected back along the reference line. The output of differential amplifier **38** may be recorded and the time interval between the two null signals ascertained. This time interval is then a measure of the angular position of reflector **22** with respect to reference line **14**.

It will be understood that the invention is not to be limited to the details given herein but that it may be modified within the scope of the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An apparatus for determining the spatial relationship between a reference line and an object point spaced therefrom comprising:

(a) means for generating and transmitting a light beam along the reference line,

(b) a first rotatable mirror on the reference line for reflecting the light beam to the object point,

(c) means at the object point for reflecting the light beam back along the reference line via the first rotatable mirror,

(d) first means for detecting deviation from the reference line of the beam reflected from the object point via the first rotatable mirror,

(e) first means responsive to the first detecting means for rotating the first rotatable mirror to produce a null deviation between the reference line and the beam reflected from the object point via the first rotatable mirror, and

(f) first means for measuring the angle of rotation of the first rotatable mirror as a measure of the spatial relationship between the object point and the reference line.

2. The apparatus of claim **1** further including:

(a) a second rotatable mirror on the reference line for reflecting the light beam to the object point,

(b) means at the object point for reflecting the light beam back along the reference line via the second rotatable mirror,

(c) second means for detecting deviation from the reference line of the beam reflected from the object point via the second rotatable mirror,

(d) second means responsive to the second detecting means for rotating the second rotatable mirror to produce a null deviation between the reference line and the beam reflected from the object point via the second rotatable mirror, and

(e) second means for measuring the angle of rotation of the second rotatable mirror.

3. The apparatus of claim 2 wherein the light-generating means produces a collimated beam circular in cross section and the reflecting means at the object point comprises a curved reflecting surface so that light reflected therefrom is elliptical in cross section.

4. The apparatus of claim 3 wherein the means for detecting deviation of the elliptical reflected beams from the reference line comprises means for splitting each of the elliptical reflected beams into first and second signals which are intensity dependent upon deviation of the elliptical reflected beam from the reference line, and means for comparing said first and second signals, said comparing means being adapted to produce a signal indicative of the extent and direction of deviation of the elliptical reflected beam from the reference line.

5. The apparatus of claim 4 wherein the means for rotating the rotatable mirrors each comprise a motor and a shaft driven by the motor in communication with the rotatable mirror, said motor being activated by the signal produced by the comparing means.

6. The apparatus of claim 5 wherein the means for measuring the angle of rotation of the rotatable mirror each comprise a resolver having a rotor attached to the shaft in communication with the rotatable mirror, a stator with a pair of quadrature-wound windings, means for generating a pair of reference signals in phase quadrature with respect to each other and exciting each of said stator windings with one of the reference signals to induce in said rotor a signal phase dependent upon the rotational position of the shaft, and means for comparing the phases of the signal in the rotor and one of the reference signals.

7. The apparatus of claim 6 and further comprising a counter, said counter being activated when a signal from the means for comparing the phases of the signal in the rotor and one of the reference signals is positive and said counter being deactivated when said signal from the comparing means is negative.

8. The apparatus of claim 6 wherein the means for splitting the elliptical reflected beam each comprise a wedge having silvered slanted sides and a hole of sufficient diameter to admit the collimated beam circular in cross section therethrough, said hole extending from the knife-edge to the back of said wedge and said wedge being positioned along said reference line.

9. The apparatus of claim 7 wherein the means for producing a collimated beam of light circular in cross section is a continuous wave laser.

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